CLAIMS

What is claimed is:

1. A micro-electromechanical optical switch assembly comprising:

a substrate and a cover disposed over an upper surface of the substrate;

an array of input optical fibers and an array of output optical fibers supported by the substrate;

an array of input reflective switching elements, each one of the input switching elements disposed to receive light transmitted from an associated input optical fiber, each of the input switching elements rotatably supported by the substrate for rotation about an axis parallel with an end portion of the associated input optical fiber;

an array of output reflective switching elements, each one of the output switching elements disposed to transmit light to an associated output optical fiber, each of the output switching elements rotatably supported by the substrate for rotation about an axis parallel with an end portion of the associated output optical fiber;

an intermediate reflective element supported by the cover on an optical path between the input switching elements and the output switching elements and disposed to direct light received from the input switching elements to the output switching elements; and

an actuating mechanism operative to control rotation of the input switching elements and the output switching elements.

2. The micro-electromechanical optical switch assembly of claim 1, wherein the actuating mechanism is operative to rotate a selected one of the input switching elements to a

position to direct light to a selected one of the output switching elements, and to rotate a selected one of the output switching elements to a position to direct light to a selected one of the output optical fibers.

3. The micro-electromechanical optical switch assembly of claim 1, wherein each of the input switching elements and each of the output switching elements are supported by torsional springs aligned for torsional rotation along the rotation axis.

4. The micro-electromechanical optical switch assembly of claim 3, wherein the torsional springs include stiffening members configured to minimize bending deflection.

5. The micro-electromechanical optical switch assembly of claim 4, wherein the stiffening members comprise at least one rib formed to extend from a beam of the torsional springs.

6. The micro-electromechanical optical switch assembly of claim 4, wherein the stiffening members comprise a stepped protrusion formed in the torsional springs.

7. The micro-electromechanical optical switch assembly of claim 3, wherein the actuating mechanism further comprises actuation pads on the torsional springs and cooperative with further actuation pad on the substrate.

8. The micro-electromechanical optical switch assembly of claim 3, wherein the actuating mechanism further comprises actuation pads on a bridge extending over each of the switching elements and cooperative with further actuation pads on the substrate.

9. The micro-electromechanical optical switch assembly of claim 3, wherein the actuating mechanism further comprises actuation pads on cantilever members extending from each of the switching elements over the substrate and cooperative with further actuation pads on the substrate.

10. The micro-electromechanical optical switch assembly of claim 9, wherein the cantilever members include stop tabs extending therefrom configured to contact the substrate upon sufficient rotation of the switching element.

11. The micro-electromechanical optical switch assembly of claim 1, wherein the input switching elements and the output switching elements are integrally formed in the substrate.

12. The micro-electromechanical optical switch assembly of claim 11, wherein the substrate comprises a semiconductor wafer.

13. The micro-electromechanical optical switch assembly of claim 1, wherein the input switching elements and the output switching elements are sized to minimize loss of light from the input optical fibers to the output optical fibers.

14. The micro-electromechanical optical switch assembly of claim 1, wherein the array of input optical fibers and the array of input switching elements, and the array of output optical fibers and the array of output switching elements are each linear.

15. The micro-electromechanical optical switch assembly of claim 1, wherein the array of input optical fibers and the

array of input switching elements, and the array of output optical fibers and the array of output switching elements are each two-dimensional.

16. The micro-electromechanical optical switch assembly of claim 15, wherein each of the input switching elements and each of the output switching elements are supported by further torsional springs aligned for torsional rotation along a further axis orthogonal to the rotation axis.

17. The micro-electromechanical optical switch assembly of claim 1, wherein each of the input switching elements and each of the output switching elements are supported by further torsional springs aligned for torsional rotation along a further axis orthogonal to the rotation axis.

18. The micro-electromechanical optical switch assembly of claim 1, wherein the intermediate reflective element is fixed to the cover.

19. The micro-electromechanical optical switch assembly of claim 1, wherein the intermediate reflective element comprises a mirror.

20. The micro-electromechanical optical switch assembly of claim 1, wherein the intermediate reflective element comprises an elongated reflective member disposed to extend a length of the array of input optical fibers and the array of output optical fibers.

21. The micro-electromechanical optical switch assembly of claim 1, wherein the intermediate reflective element comprises

a plurality of reflective members associated with each of the input switching elements.

22. The micro-electromechanical optical switch assembly of claim 1, wherein the input optical fibers and the output optical fibers are each supported in grooves formed in the substrate.

23. The micro-electromechanical optical switch assembly of claim 22, further comprising further grooves formed in the cover corresponding to the grooves formed in the substrate.

24. The micro-electromechanical optical switch assembly of claim 1, further comprising an alignment device disposed to cooperatively align the substrate and the cover.

25. The micro-electromechanical optical switch assembly of claim 24, wherein the alignment device comprises a protrusion on one of the cover and the substrate and a corresponding depression on the other of the cover and the substrate.

26. The micro-electromechanical optical switch assembly of claim 24, wherein the alignment device comprises corresponding depressions formed in the cover and the substrate and a free element disposed within the corresponding depressions.

27. The micro-electromechanical optical switch assembly of claim 24, further comprising:

a bottom cover; and

the alignment device comprises a hole through the substrate, and a corresponding depression in one of the cover and the bottom cover, and a protrusion on the other of the

cover and the bottom cover disposed to extend through the hole and into the corresponding depression.

28. The micro-electromechanical optical switch assembly of claim 1, further comprising a collimating optical component disposed adjacent an end of each of the input optical fibers.

29. The micro-electromechanical optical switch assembly of claim 28, wherein the collimating optical component comprises a ball lens or a gradient index lens.

30. The micro-electromechanical optical switch assembly of claim 1, further comprising:

an input lower optical turning element and an input upper optical turning element;

the input lower optical turning element disposed to reflect light from the input optical fiber to the input upper optical turning element; and

the input upper optical turning element disposed to reflect light to a selected one of the input switching elements.

31. The micro-electromechanical optical switch assembly of claim 30, wherein the input lower optical turning element is supported by the substrate; and

the input upper optical turning element is supported by the cover.

32. The micro-electromechanical optical switch assembly of claim 30, wherein the input lower optical turning element is fixedly supported by the substrate.

33. The micro-electromechanical optical switch assembly of claim 30, wherein the input lower optical turning element is supported in a groove formed in the substrate.

34. The micro-electromechanical optical switch assembly of claim 30, wherein the input lower optical turning element comprises an elongated mirror.

35. The micro-electromechanical optical switch assembly of claim 30, wherein the input lower optical turning element comprises a plurality of mirrors.

36. The micro-electromechanical optical switch assembly of claim 30, wherein the input lower optical turning element comprises a reflective coating on a surface of the substrate.

37. The micro-electromechanical optical switch assembly of claim 30, wherein the input lower optical turning element comprises a mirror attached to a surface of the substrate.

38. The micro-electromechanical optical switch assembly of claim 37, wherein the mirror is wedge-shaped.

39. The micro-electromechanical optical switch assembly of claim 30, wherein the cover is optically transparent and includes a protrusion extending into a groove formed in the substrate, and the input lower optical turning element is supported on the protrusion.

40. The micro-electromechanical optical switch assembly of claim 39, wherein the input lower optical turning element comprises a reflective coating formed on a surface of the protrusion.

41. The micro-electromechanical optical switch assembly of claim 39, wherein the input lower optical turning element comprises an internal reflective surface formed on the protrusion.

42. The micro-electromechanical optical switch assembly of claim 30, wherein the input lower optical turning element comprises a collimating optical element.

43. The micro-electromechanical optical switch assembly of claim 42, wherein the collimating optical element comprises a curved mirror.

44. The micro-electromechanical optical switch assembly of claim 30, wherein the input upper optical turning element comprises a mirror embedded in the cover.

45. The micro-electromechanical optical switch assembly of claim 44, wherein the mirror is shaped to collimate light from a selected one of the input optical fibers.

46. The micro-electromechanical optical switch assembly of claim 30, wherein the upper optical turning element comprises a mirror and a lens, the lens configured to collimate light transmitted from a selected one of the input optical fibers.

47. The micro-electromechanical optical switch assembly of claim 30, wherein the input upper optical turning element is operative to collimate light transmitted from a selected one of the input optical fibers.

48. The micro-electromechanical optical switch assembly of claim 30, wherein the input upper optical turning element is fixedly supported on the cover.

49. The micro-electromechanical optical switch assembly of claim 30, wherein the input upper optical turning element comprises a mirror.

50. The micro-electromechanical optical switch assembly of claim 49, wherein the mirror is shaped to collimate light from a selected input optical fiber.

51. The micro-electromechanical optical switch assembly of claim 30, wherein the input upper optical turning element comprises a plurality of mirrors, each mirror associated with a selected input optical fiber.

52. The micro-electromechanical optical switch assembly of claim 51, wherein each mirror is shaped to collimate light from the input optical fiber.

53. The micro-electromechanical optical switch assembly of claim 1, further comprising:

an output lower optical turning element and an output upper optical turning element;

the output upper optical turning element disposed to reflect light from a selected one of the output switching elements to the output lower optical turning element; and

the output lower optical turning element disposed to reflect light to a selected one of the output optical fibers.

54. The micro-electromechanical optical switch assembly of claim 53, wherein the output upper optical turning element is

operative to focus light from the selected one of the output switching elements.

55. The micro-electromechanical optical switch assembly of claim 53, wherein the output lower optical turning element is supported by the substrate, and

the output upper optical turning element is supported by the cover.

56. The micro-electromechanical optical switch assembly of claim 53, wherein the output lower optical turning element is fixedly supported on the substrate.

57. The micro-electromechanical optical switch assembly of claim 53, wherein the output lower optical turning element comprises an elongated mirror.

58. The micro-electromechanical optical switch assembly of claim 53, wherein the output lower optical turning element comprises a plurality of mirrors.

59. The micro-electromechanical optical switch assembly of claim 53, wherein the output lower optical turning element comprises a reflective coating on a surface of the substrate.

60. The micro-electromechanical optical switch assembly of claim 53, wherein the output lower optical turning element comprises a mirror attached to a surface of the substrate.

61. The micro-electromechanical optical switch assembly of claim 60, wherein the mirror is wedge-shaped.

62. The micro-electromechanical optical switch assembly of claim 53, wherein the cover is optically transparent and includes a protrusion extending into a groove formed in the substrate, and the output lower optical turning element is supported on the protrusion.

63. The micro-electromechanical optical switch assembly of claim 62, wherein the output lower optical turning element comprises a reflective coating formed on a surface of the protrusion.

64. The micro-electromechanical optical switch assembly of claim 62, wherein the output lower optical turning element comprises an internal reflective surface formed on the protrusion.

65. The micro-electromechanical optical switch assembly of claim 53, wherein the output lower optical turning element comprises a focusing optical element.

66. The micro-electromechanical optical switch assembly of claim 65, wherein the focusing optical element comprises a curved mirror.

67. The micro-electromechanical optical switch assembly of claim 53, wherein the output upper optical turning element comprises a mirror embedded in the cover.

68. The micro-electromechanical optical switch assembly of claim 67, wherein the mirror is shaped to focus light to a selected one of the output optical fibers.

69. The micro-electromechanical optical switch assembly of claim 53, wherein the upper optical turning element comprises a mirror and a lens, the lens configured to focus light to a selected one of the output optical fibers.

70. The micro-electromechanical optical switch assembly of claim 53, wherein the output upper optical turning element is operative to focus light to a selected one of the output optical fibers.

71. The micro-electromechanical optical switch assembly of claim 53, wherein the output upper optical turning element is fixedly supported on the cover.

72. The micro-electromechanical optical switch assembly of claim 53, wherein the output upper optical turning element comprises a mirror.

73. The micro-electromechanical optical switch assembly of claim 72, wherein the mirror is shaped to focus light from the output switching element.

74. The micro-electromechanical optical switch assembly of claim 53, wherein the output upper optical turning element comprises a plurality of mirrors, each mirror associated with a selected output optical fiber.

75. The micro-electromechanical optical switch assembly of claim 74, wherein each mirror is shaped to focus light from the output switching element.

76. The micro-electromechanical optical switch assembly of claim 1, wherein the array of input optical fibers and the

array of output optical fibers are aligned in grooves formed in the substrate.

77. The micro-electromechanical optical switch assembly of claim 76, wherein the cover includes a plurality of grooves formed therein in alignment with the grooves formed in the substrate.

78. The micro-electromechanical optical switch assembly of claim 1, wherein the cover is formed of an optically transparent material.

79. The micro-electromechanical optical switch assembly of claim 1, further comprising a bottom cover fixed to a lower surface of the substrate.

80. The micro-electromechanical optical switch assembly of claim 1, wherein a sealed cavity is provided in the substrate surrounding the optical switching elements.

81. The micro-electromechanical optical switch assembly of claim 80, further comprising:

a bottom cover disposed over a lower surface of the substrate; and

the sealed cavity is defined between the cover and bottom cover.

82. The micro-electromechanical optical switch assembly of claim 80, wherein the sealed cavity is filled with air, an inert gas, or a vacuum.

83. The micro-electromechanical optical switch assembly of claim 80, wherein the sealed cavity is filled with an

optically transparent, non-electrically conductive dielectric liquid.

84. The micro-electromechanical optical switch assembly of claim 83, wherein the liquid comprises an oil or glycerin.

85. The micro-electromechanical optical switch assembly of claim 80, wherein the sealed cavity is filled with a liquid selected to provide damping of the switching elements.

86. The micro-electromechanical optical switch assembly of claim 80, wherein the sealed cavity is filled with a liquid selected to provide shock resistance.

87. The micro-electromechanical optical switch assembly of claim 80, wherein the sealed cavity is filled with a liquid having a dielectric constant selected to amplify electrostatic force acting on the switching elements.

88. The micro-electromechanical optical switch assembly of claim 80, wherein the sealed cavity is filled with a liquid having an index of refraction selected to reduce optical divergence of light transmitted through the sealed cavity.

89. The micro-electromechanical optical switch assembly of claim 80, wherein the sealed cavity is filled with a fluorinated solvent.

90. The micro-electromechanical optical switch assembly of claim 1, further comprising an optical detector element disposed on an optical path and in communication with the actuating mechanism.

91. The micro-electromechanical optical switch assembly of claim 90, wherein the optical detector element is disposed behind the input switching element.

92. The micro-electromechanical optical switch assembly of claim 90, wherein the optical detector element is disposed at an end of the input optical fibers.

93. The micro-electromechanical optical switch assembly of claim 90, further comprising:

an input optical turning element disposed to reflect light from the input optical fiber to the input turning element; and

the optical detector element is disposed behind the input optical turning element.

94. The micro-electromechanical optical switch assembly of claim 93, wherein the input optical turning element is supported by the substrate.

95. The micro-electromechanical optical switch assembly of claim 93, wherein the input optical turning element is supported by the cover.

96. The micro-electromechanical optical switch assembly of claim 90, further comprising:

an output optical turning element disposed to transmit light from to the output switching element to the output optical fiber; and

the optical detector element is disposed behind the output optical turning element.

97. The micro-electromechanical optical switch assembly of claim 96, wherein the output optical turning element is supported by the substrate.

98. The micro-electromechanical optical switch assembly of claim 96, wherein the output optical turning element is supported by the cover.

99. The micro-electromechanical optical switch assembly of claims 1, 16, or 17, wherein the actuating mechanism comprises first actuation pads on a bottom of each of the input and output reflective switching elements and second actuation pads supported on a bottom surface of the substrate in opposition to the first actuation pads.

100. The micro-electromechanical optical switch assembly of claim 99, wherein the second actuation pads extend parallel to the respective rotation axis of an associated one of the input and output reflective switching elements.

101. The micro-electromechanical optical switch assembly of claim 99, wherein the second actuation pads are cantilevered from the bottom surface of the substrate.

102. The micro-electromechanical optical switch assembly of claims 16 or 17, wherein:

the actuating mechanism comprises first actuation pads on a bottom of each of the input and output reflective switching elements and second actuation pads supported on a bottom surface of the substrate in opposition to the first actuation pads; and

the second actuation pads extend at angle intermediate the rotation axis and the further rotation axis of an

associated one of the input and output reflective switching elements.

103. The micro-electromechanical optical switch assembly of claims 16 or 17, wherein:

the actuating mechanism comprises first actuation pads on a bottom of each of the input and output reflective switching elements and second actuation pads supported on a bottom surface of the substrate in opposition to the first actuation pads; and

the second actuation pads include pads extending parallel to the rotation axis and to the further rotation axis of an associated one of the input and output reflective switching elements.

104. The micro-electromechanical optical switch assembly of claims 1, 16, or 17, wherein the actuating mechanism comprises first actuation pads on a bottom of each of the input and output reflective switching elements and second actuation pads disposed in opposition to the first actuation pads and supported on a second substrate bonded to a lower surface of the substrate.

105. The micro-electromechanical optical switch assembly of claim 15, wherein the input fibers and the output fibers are supported in a substrate stack comprising a plurality of substrate layers.

106. The micro-electromechanical optical switch assembly of claim 105, wherein end faces of the input fibers and the output fibers protrude beyond an end face of the substrate stack.

107. The micro-electromechanical optical switch assembly of claim 105, wherein the substrate stack is mounted to a bottom surface of the substrate and the end faces of the input fibers and the output fibers extend into through-holes formed in the substrate.

108. The micro-electromechanical optical switch assembly of claim 1, further including a bottom cover, a chamber defined between the cover and the bottom cover.

109. The micro-electromechanical optical switch assembly of claim 108, wherein a cavity is defined between the cover and the bottom cover, and an optically clear fluid is disposed within the cavity.

110. The micro-electromechanical optical switch assembly of claim 109, wherein the fluid comprises a fluorinated solvent.